“A back to back Kinoform for X6A"

Kenneth Evans-Lutterodt

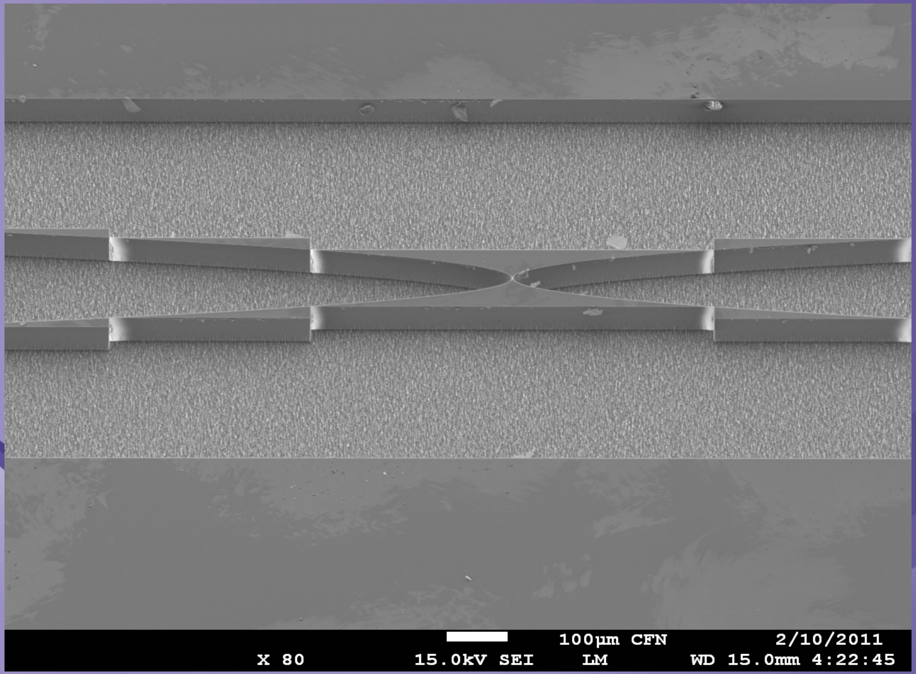
Vivian Stojanoff

Kun Qian

Jean Jakoncic

NSLS

2/14/11



SIXTY YEARS
OF DISCOVERY
1947-2007

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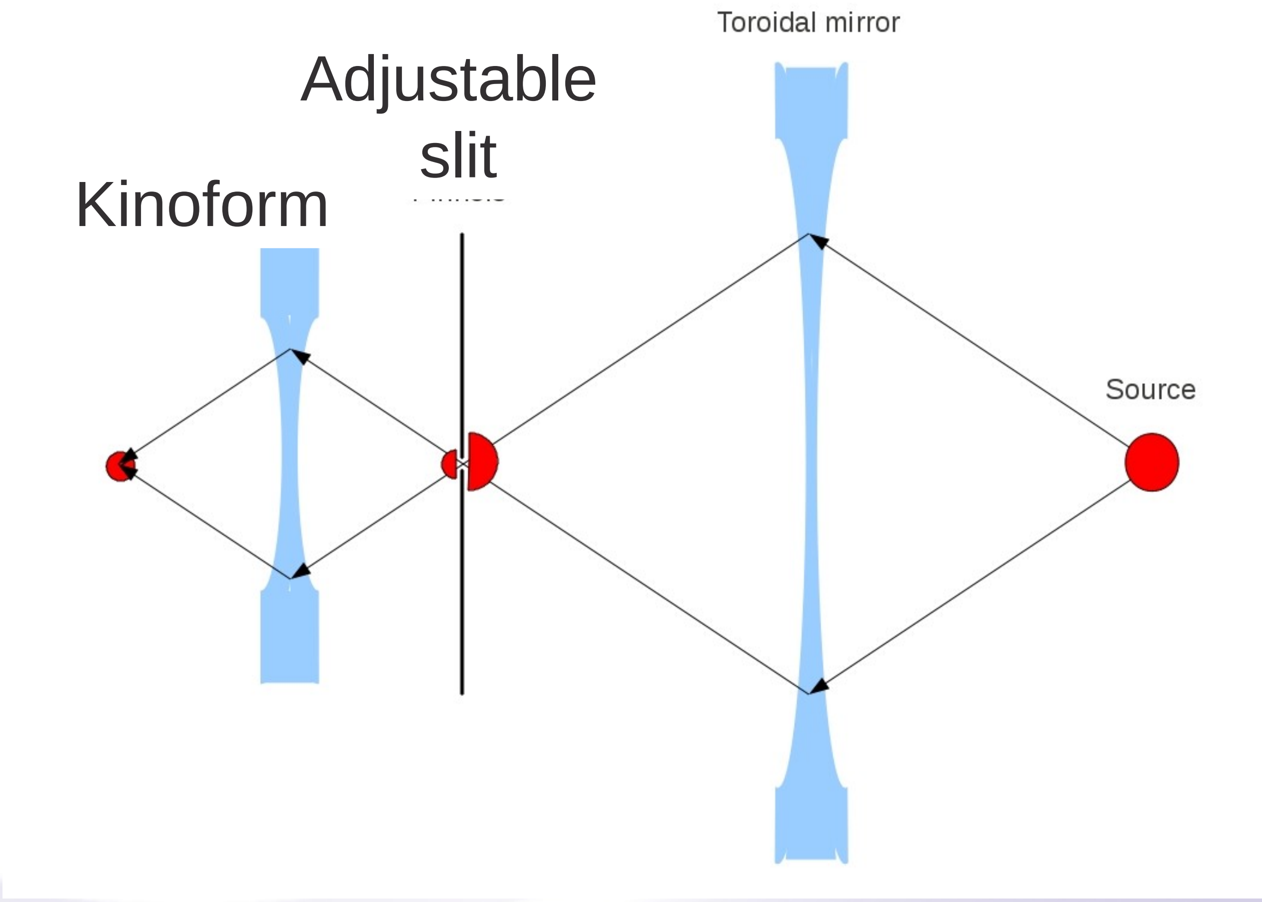
Office of Science
U.S. DEPARTMENT OF ENERGY

Outline

- Summary: What we did
- Background
- Quick introduction to kinoform
- Some other things we have done with the kinoform
- Summary

Problem: Imperfect beamlines do not focus well to give small spots;
Our solution: Implement a virtual slit using a real slit and a kinoform lens

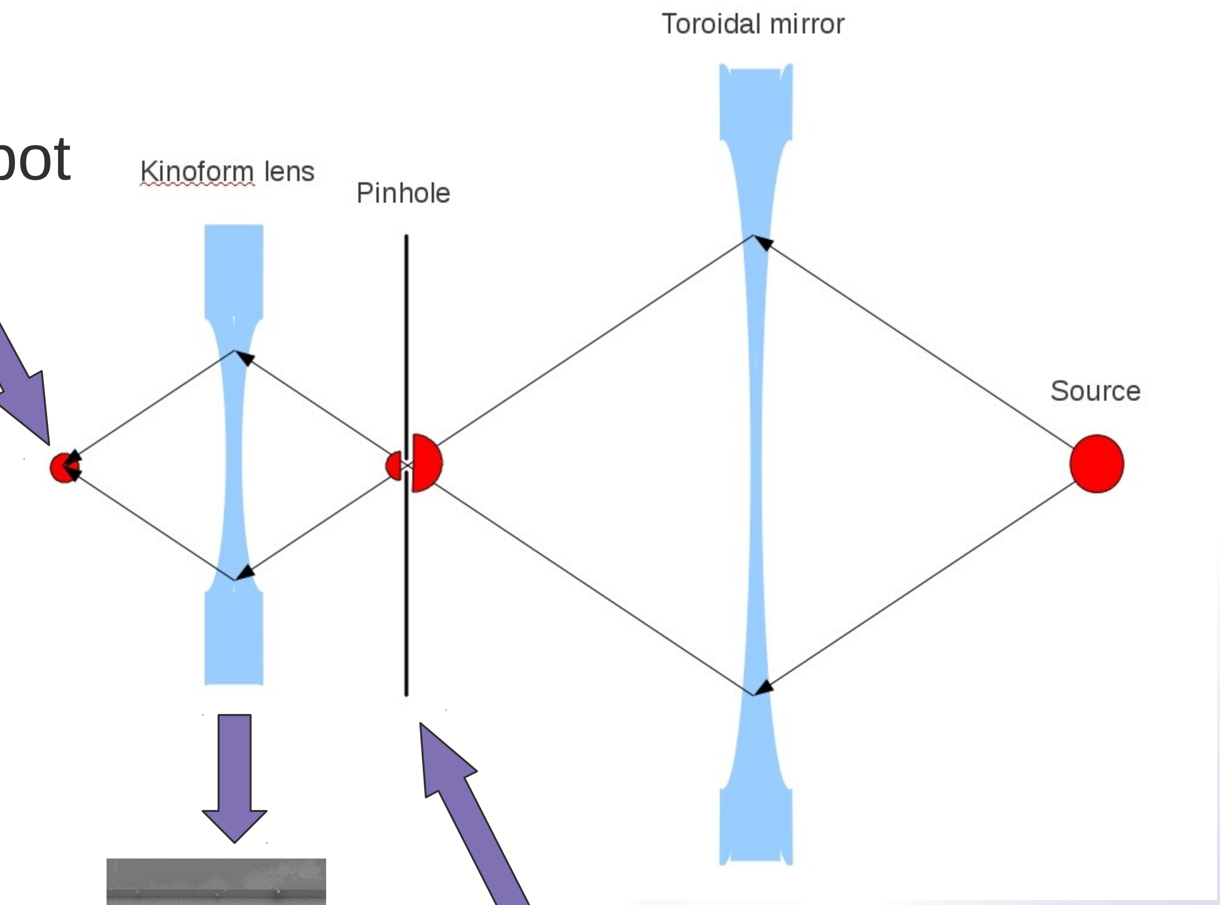


Our addition

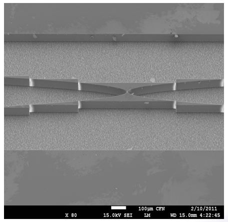
Existing beamline

What the components look like:

Measured spot



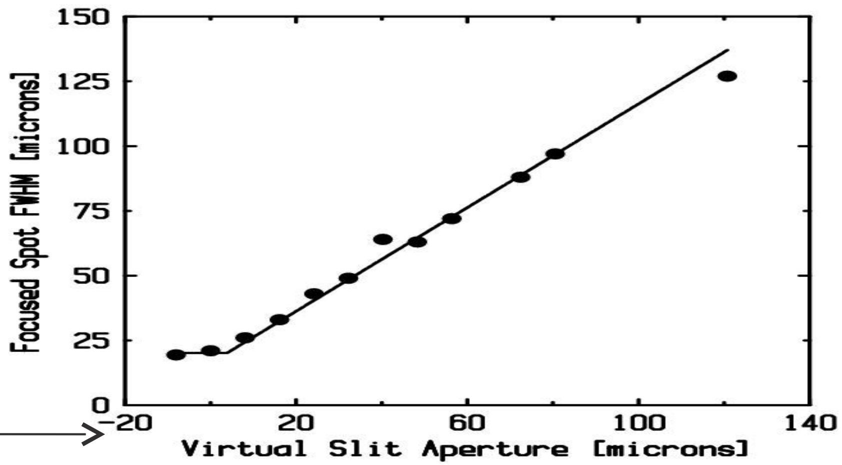
What the lens really looks like



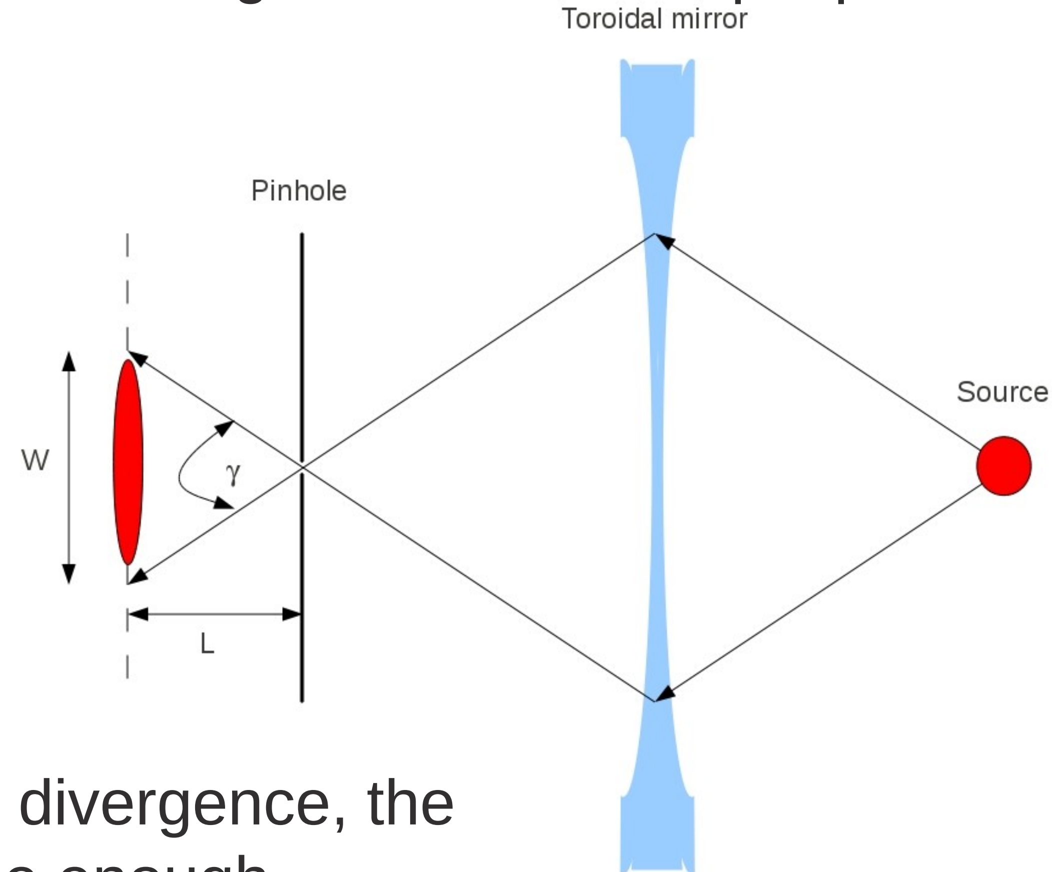
Adjustable slit ; JJXray

Result;
Measured spot at sample depends on slit size

20 microns spot,
Limited by measurement



Why can’t we use a simpler arrangement like a simple pinhole?



Answer: Given the typical divergence, the pinhole cannot be put close enough.
If $\gamma \approx$ 1mrad, L ≈ 0.3m , then W ≈ 300microns

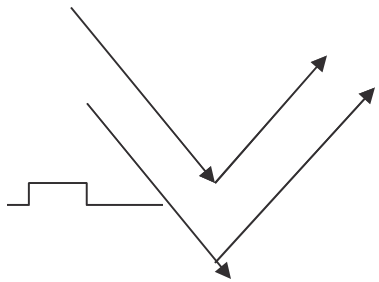
What makes a beamline imperfect?

Mirrors

Consider a mirror with a bump on it

The path length difference caused by bump is 2dsinθ

To get a π phase shift bump must be 0.25(□/□□) □25nm



Windows

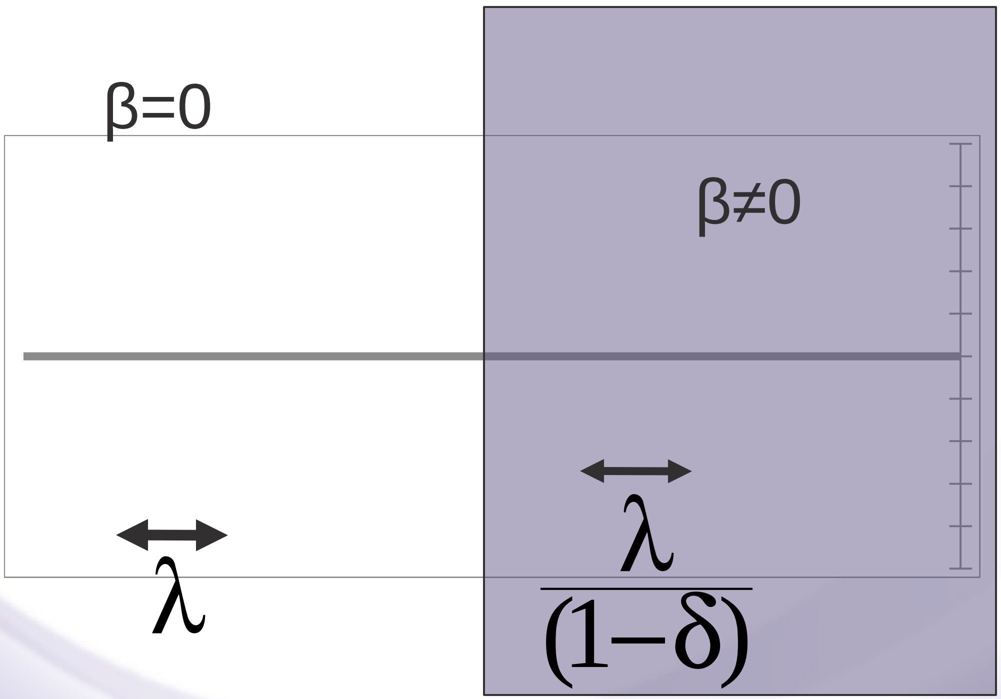
- Consider a Beryllium window
- To get a π phase shift bump must be 0.5(□/□) □15microns

A quick introduction to the kinoform

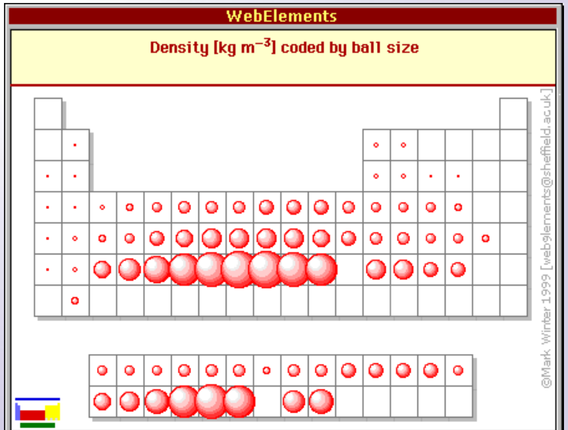
Optical Constants for Hard X-rays

Refractive index n = 1 - □ - iβ, where ▪ is ~ 10-6

Phase velocity = c/n



Refractive index set by Periodic Table



$$\mathbf{E}(\mathbf{r},t) = \underbrace{\mathbf{E}_0 e^{-i\omega(t-r/c)}}_{\text{vacuum propagation}} \underbrace{e^{-i(2\pi\delta/\lambda)r}}_{\phi\text{-shift}} \underbrace{e^{-(2\pi\beta/\lambda)r}}_{\text{decay}}$$

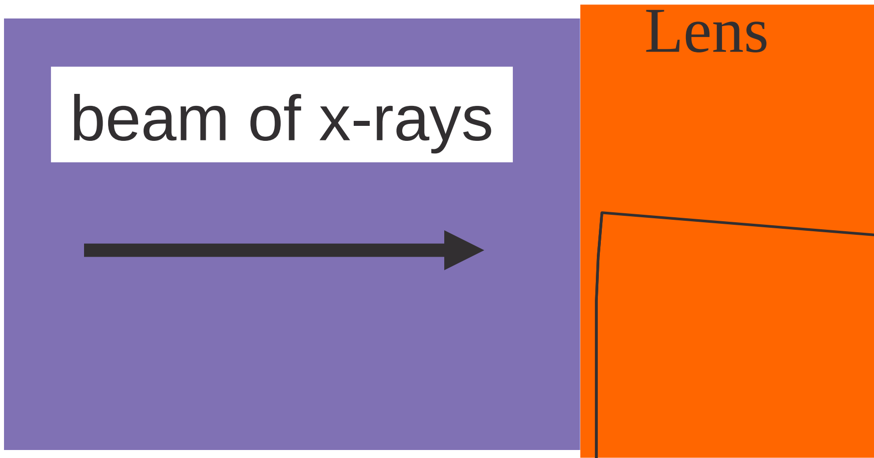
2π phase shift length $$t_{2\pi} = \frac{\lambda}{\delta}$$

Exponential Decay length (Attenuation length) $$l = \frac{\lambda}{4\pi\beta}$$

Order of magnitude:

For Si, 12keV, t2□□(10-10/3x10-6)□ 30 microns

Absorption limits aperture and resolution



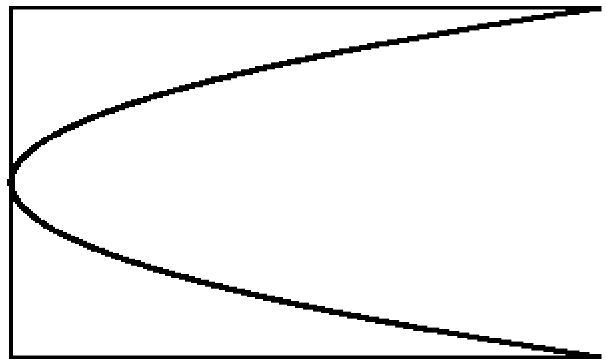
Absorption limits effective aperture of lens

Hard x-ray; n<1

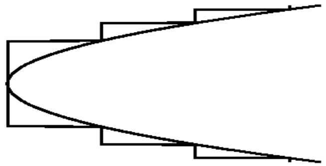
Is there a way around this?

The way around the absorption limitation: Kinoform

Instead of solid refractive optic:



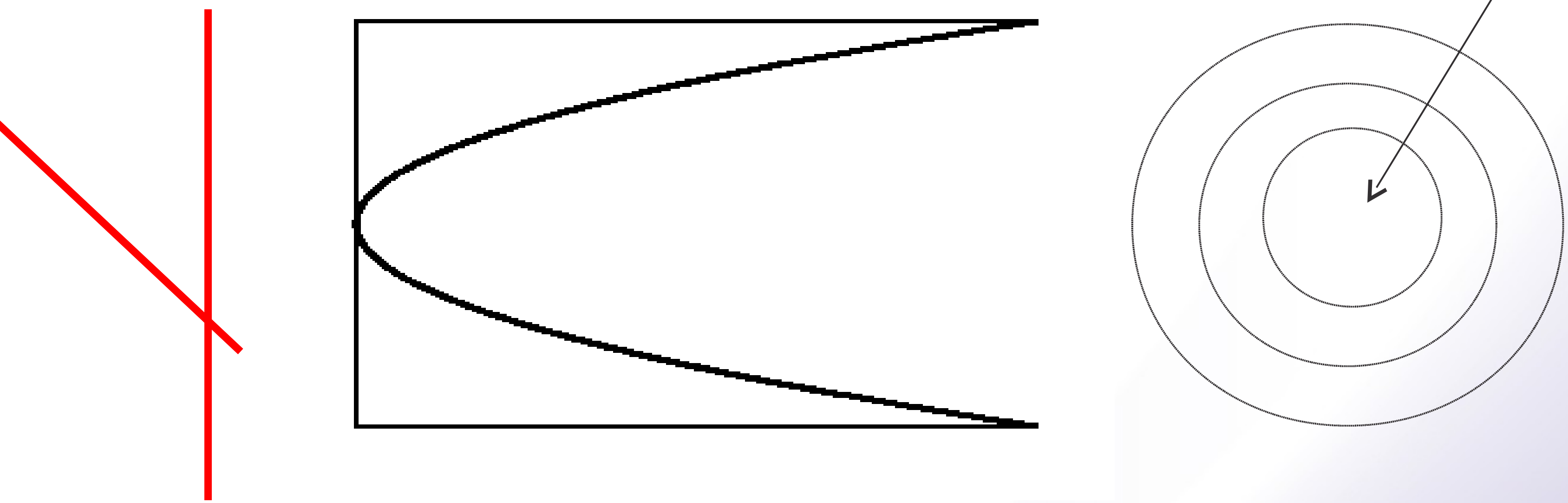
Use a kinoform (lighthouse solution):



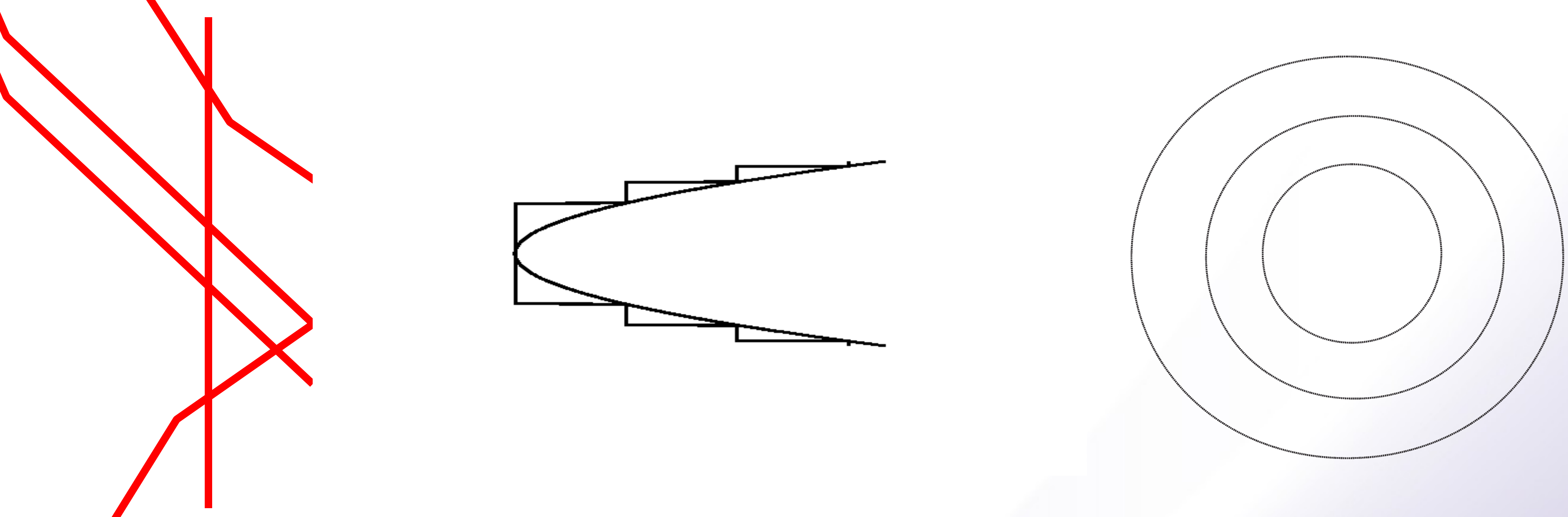
The effect of a refractive lens on single phase front

Using graphics instead of equations

$$U(P_0) = \frac{1}{i\lambda} \iint_{(\xi,\eta)} U(P_1) \frac{\exp(ikr_{01})}{r_{01}} \cos\theta \, ds$$

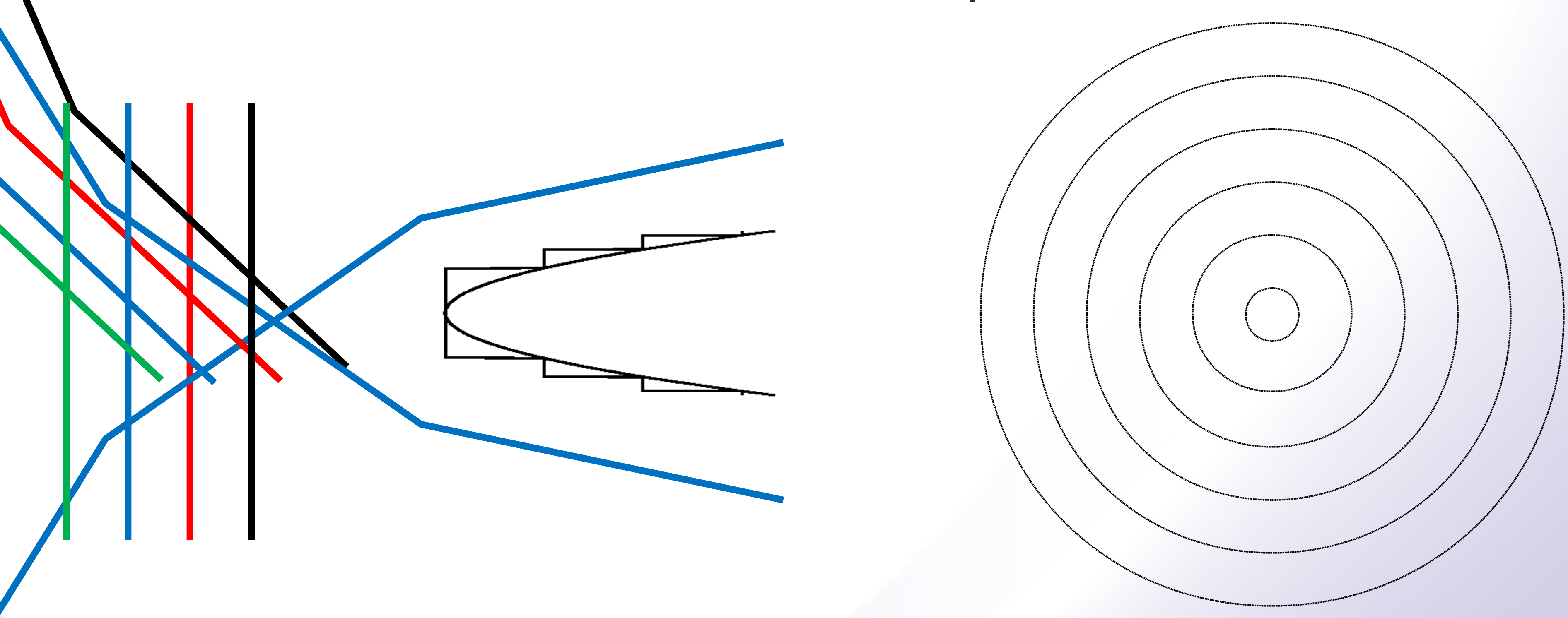


The effect of a kinoform lens on single phase front



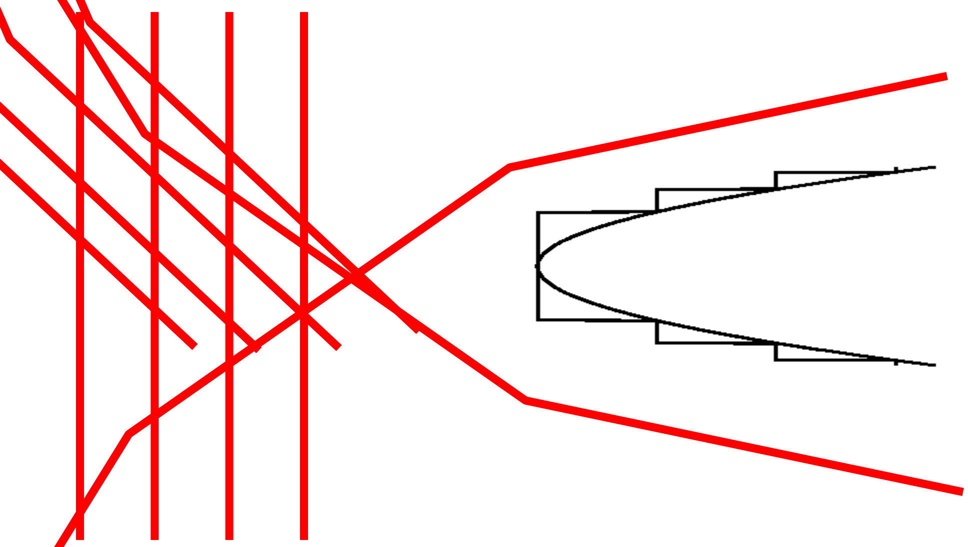
How it works (graphically)

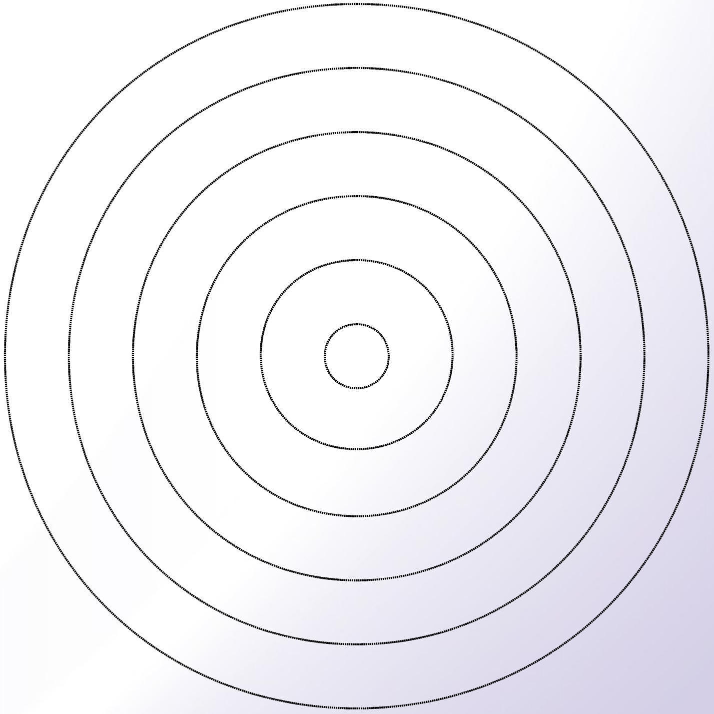
Lets follow four consecutive phase fronts



How it works (graphically)

For a long wavetrain (narrow bandwidth) it is indistinguishable





Natural match to Micro-fabrication

The amount of material to give a 2 phase shift:

$$\frac{\lambda}{\delta} = \frac{0.1\text{nm}}{3*10^{-6}} = 30\mu\text{m}$$

Micro-electronics fabrication techniques will work!

In the old days: Lucent’s Electron Beam writer JEOL 9300

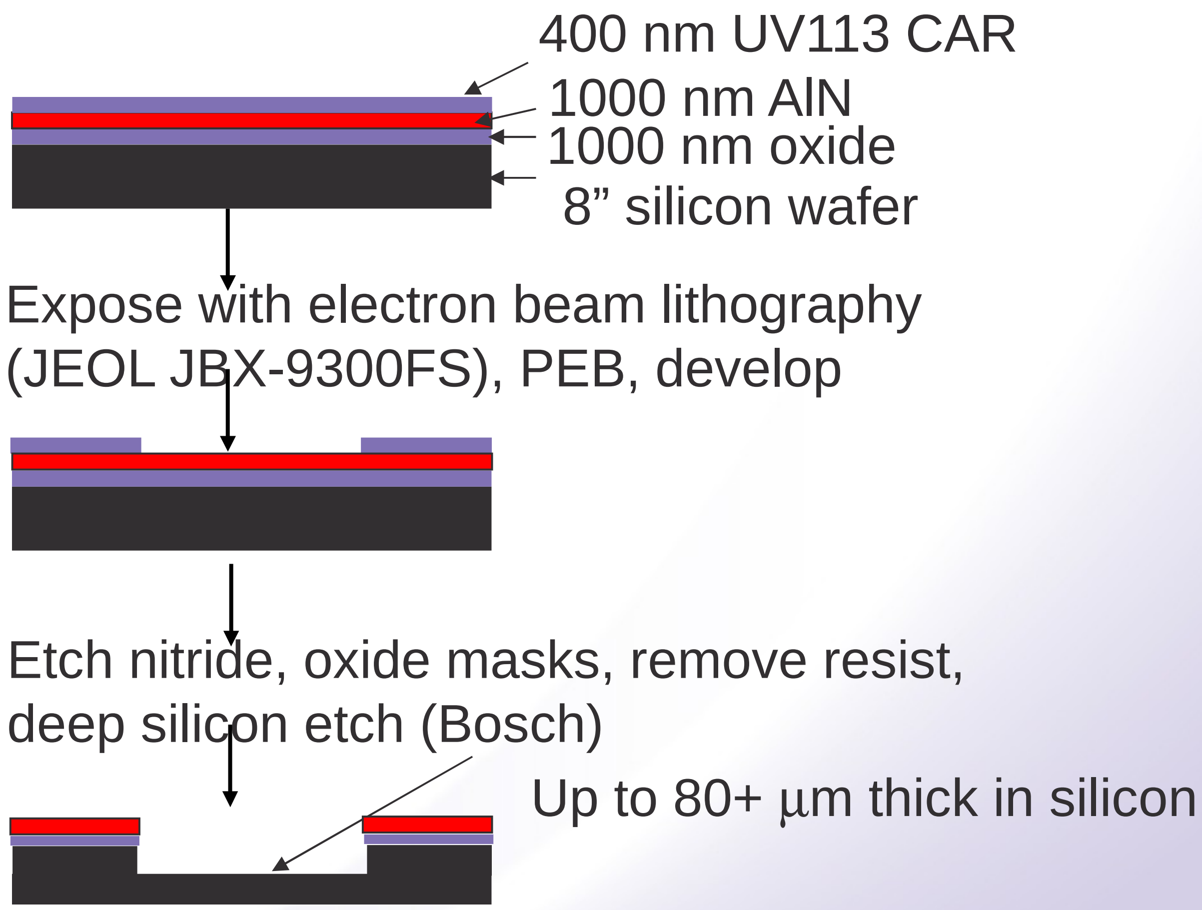
Aaron Stein
CFN

Don Tennant

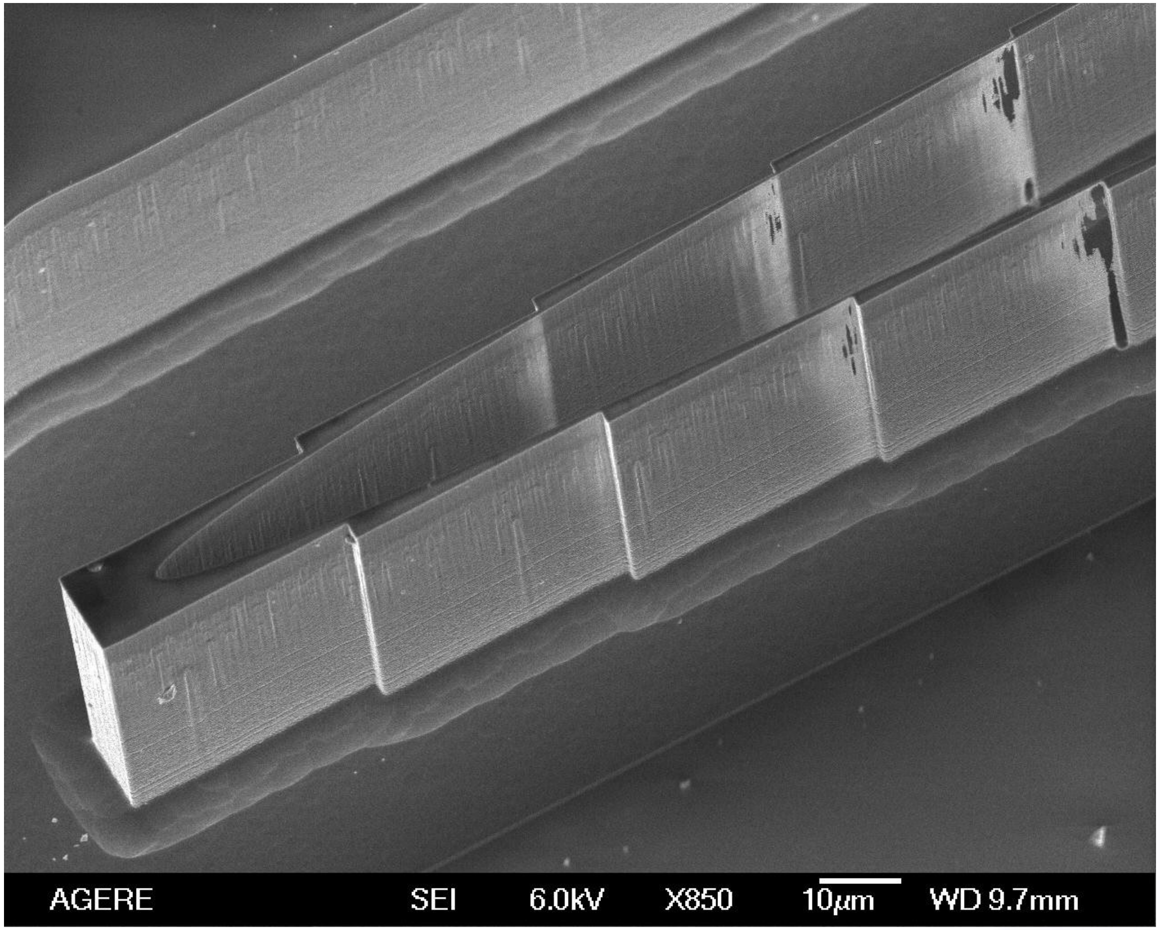
Important Characteristics:
Laser interferometer => Placement accuracy (4nm/500μm)
Flexible

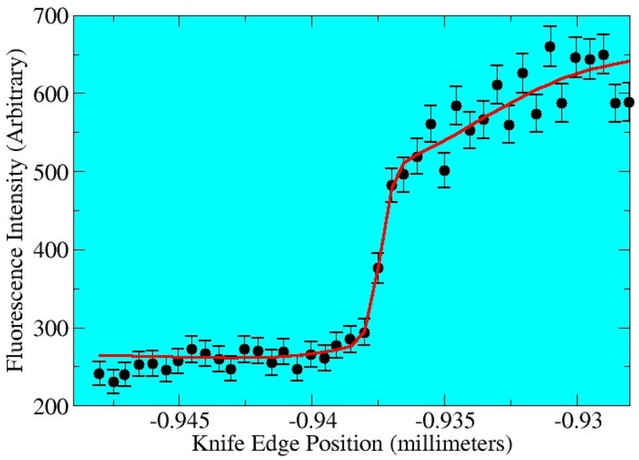
Today: E-beam at CFN/BNL and etching at CNF/Cornell

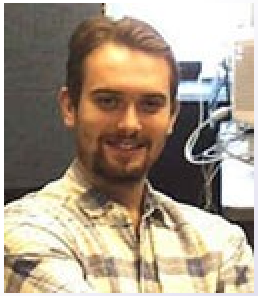
Fabrication Process Flow



Sub-micron spots with >100 micron aperture







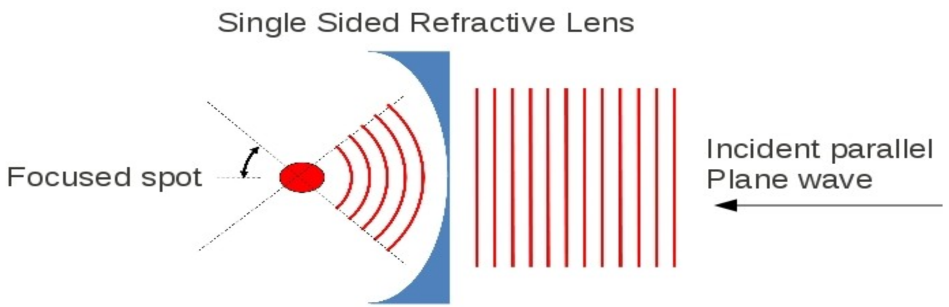
James Ablett

- Figure on right shows a knife edge scan
- Efficiency is greater than 60%

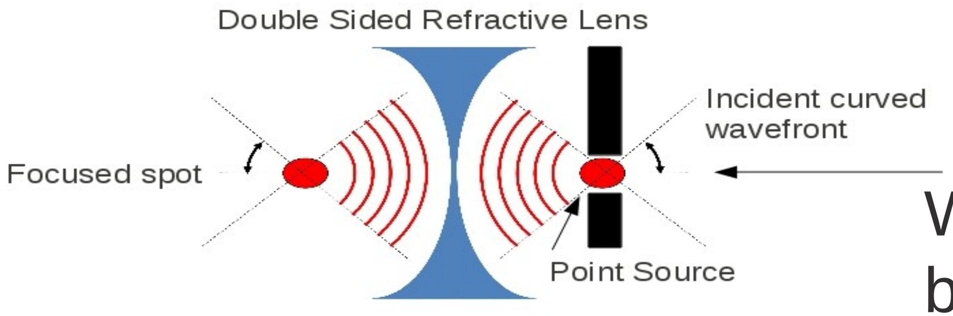
K.E-L et. Al., Optics Express, 11, 919, 2003

And now back to X6A

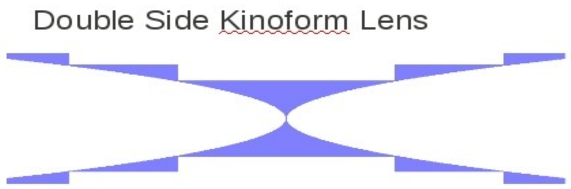
One more wrinkle for us, the source is not at infinity



This is our conventional case
the source is at infinity



We need to re-design the lens
because the source is closer



← We need to do this

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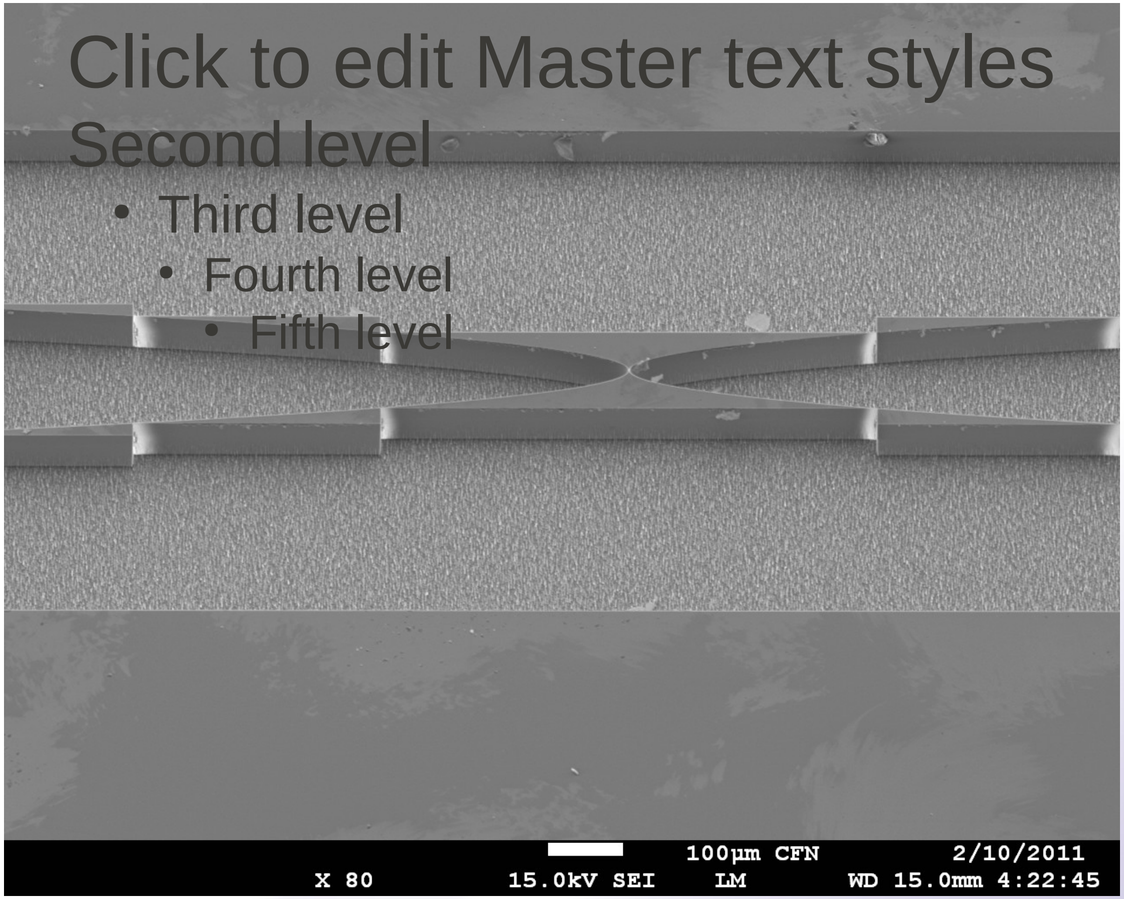
Close up view (SEM) of actual back to back kinoform lens

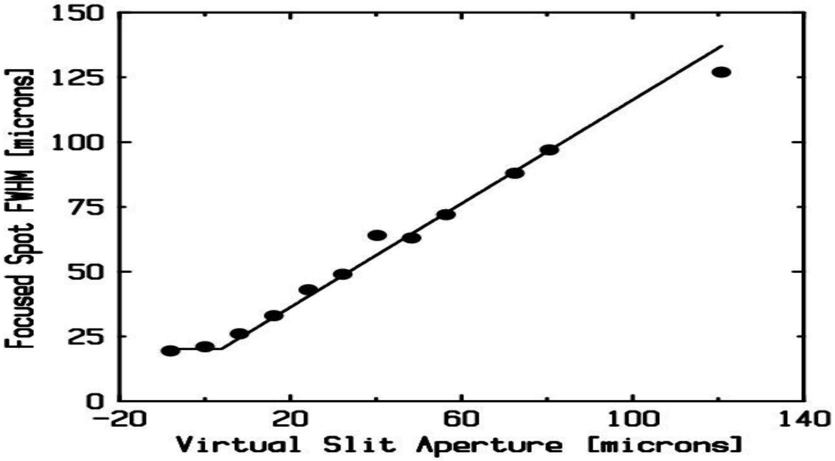
Click to edit Master text styles

Second level

- Third level
  - Fourth level
    - Fifth level

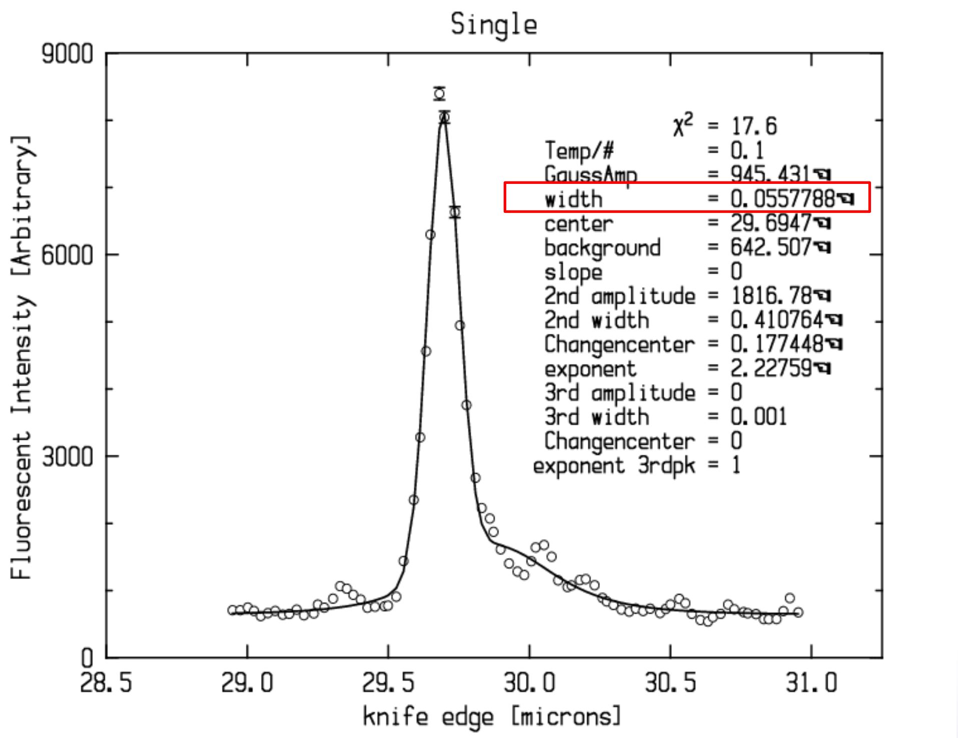


Result;
Measured spot at sample depends on to virtual slit size



Some other applications we have had for kinoforms

Diffraction limited performance from a Single Lens



Close to Diffraction limited performance

200micron aperture

Sigma = 56nm

=> FWHM=2.35σ=131nm

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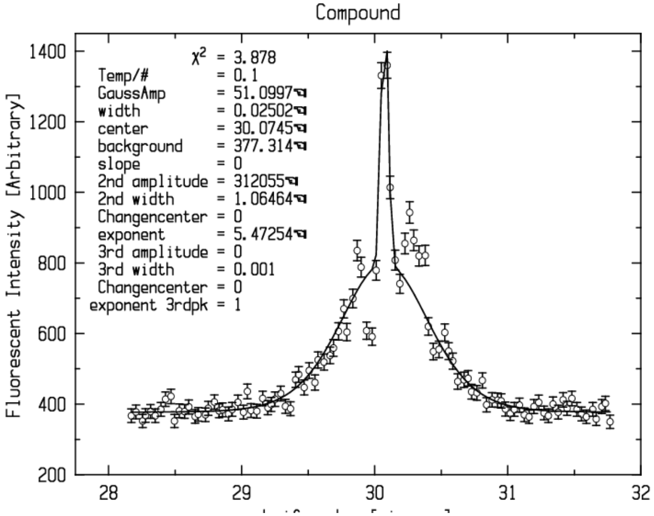
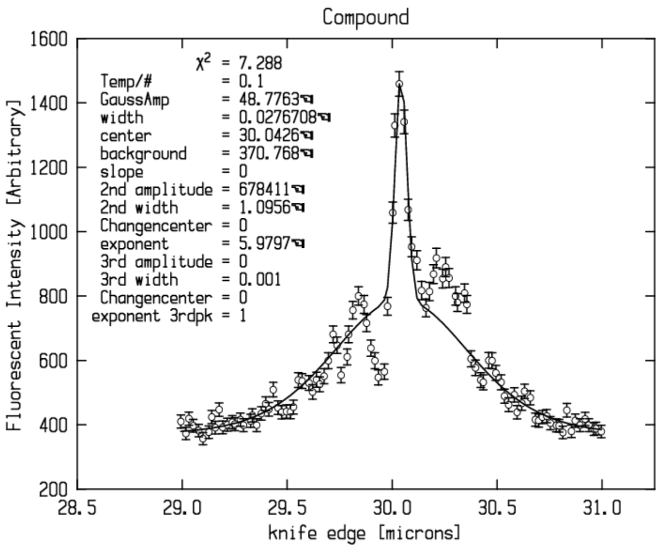
Compound Lens

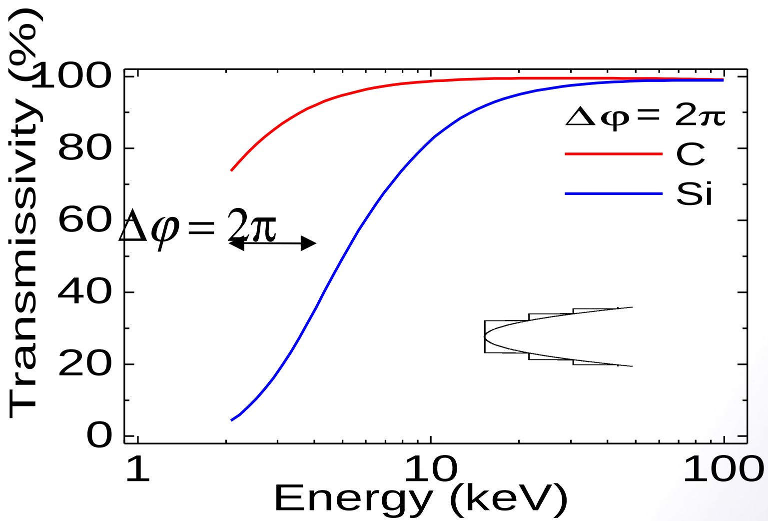




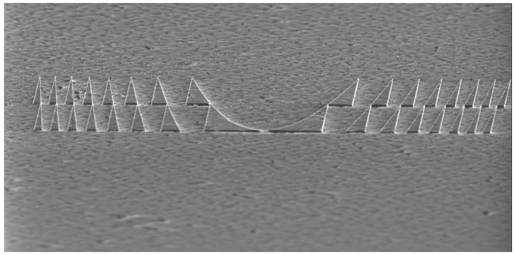
- 8 lens array
- Measurement ran out of time, not yet at best focus
- Sigma = 25nm (FWHM= 59nm)
- Knife edge is 30nm of Cr deposited on Si
- So actually the real, de-convolved performance is better !

Diamond Kinoform: fabrication and testing*

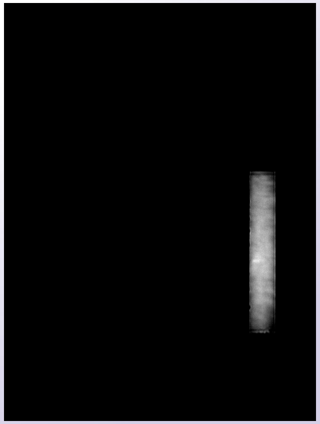
Why: Diamond has better transmission than silicon at lower energies



A real diamond lens:

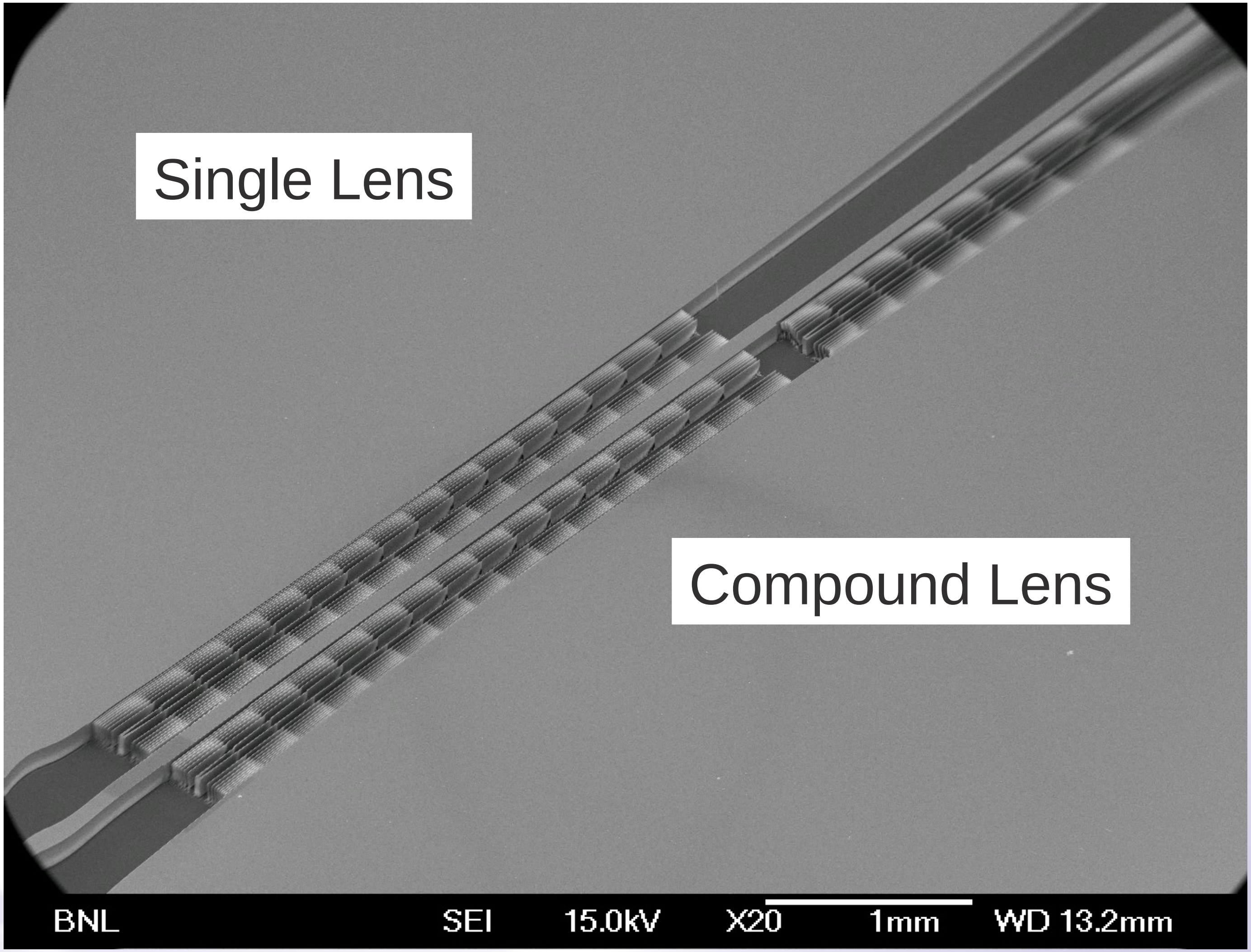


and it works!
(not very well but we know what to do next)
Line focus

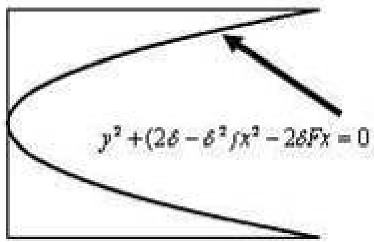


*Postdoc Abdel Isakovic will be available

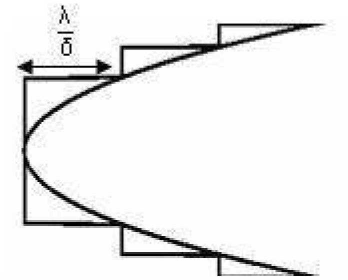
First compound lens to exceed critical angle



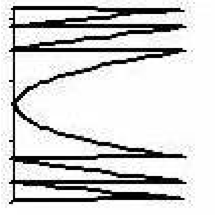
•"Using Compound Kinoform Hard-X-Ray Lenses to Exceed the Critical Angle Limit", K. Evans-Lutterodt, A. Stein, J. M. Ablett, N. Bozovic, A.Taylor and D.M.Tennant, Phys. Rev. Lett. 99, 134801 (2007)



Solid Refractive



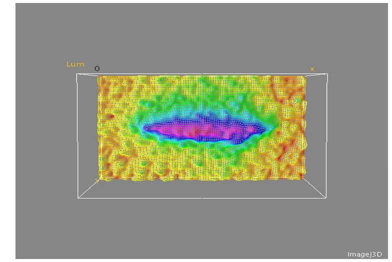
Long Kinoform



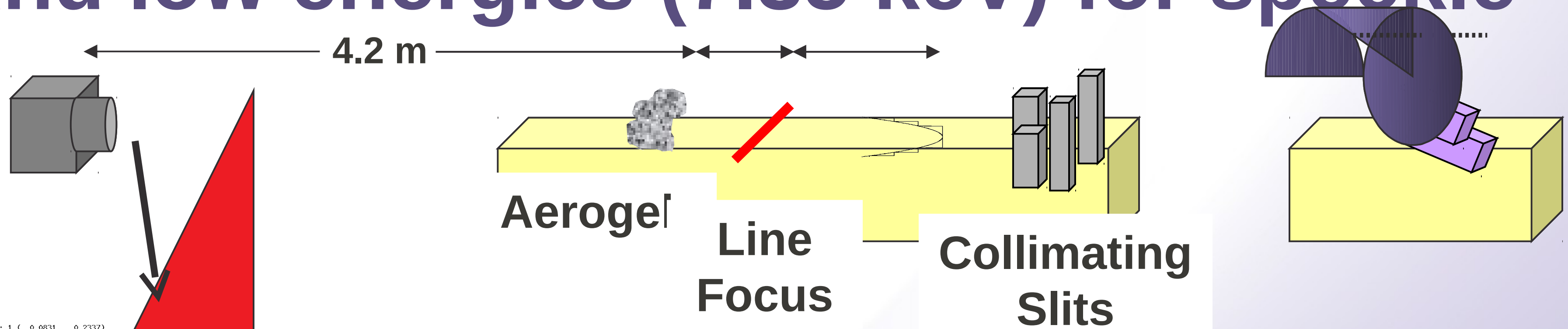
Short Kinoform

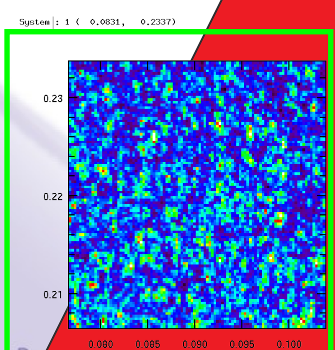
Focusing at high energies (30 keV)

Image of focused line at 30 keV (Dr Guo)
Spot size at x17 is approximately 8 microns
Applications: High Pressure, Temperature study of materials



And low energies (7.35 keV) for speckle

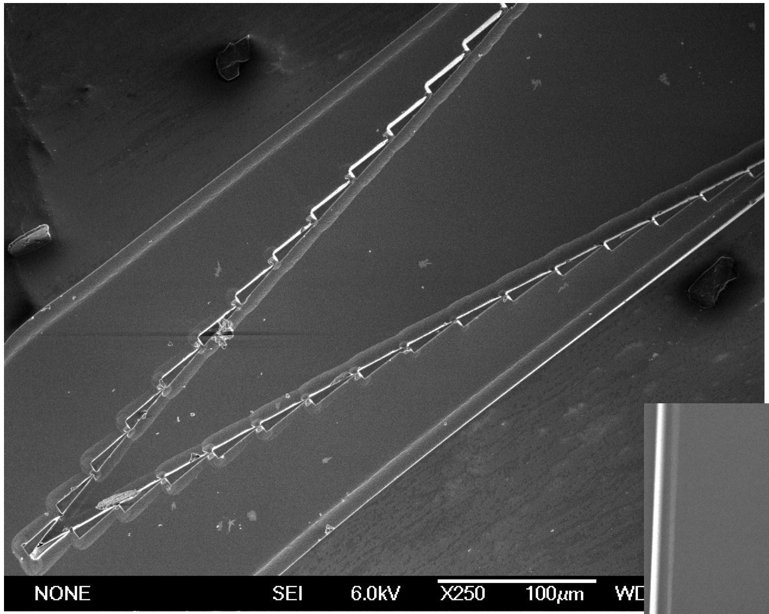


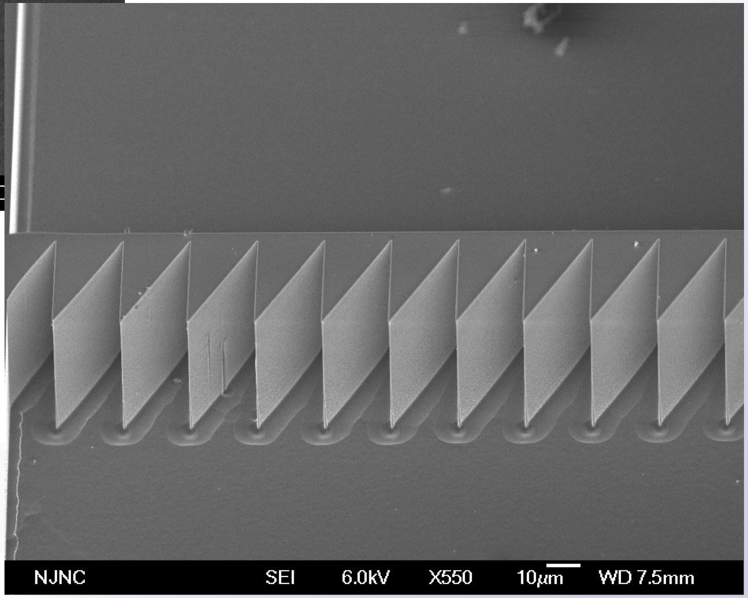


From CCD data we see that

- **Kinoform is a phase preserving optic**
- **Improve signal x2**
- **Improve contrast x2**

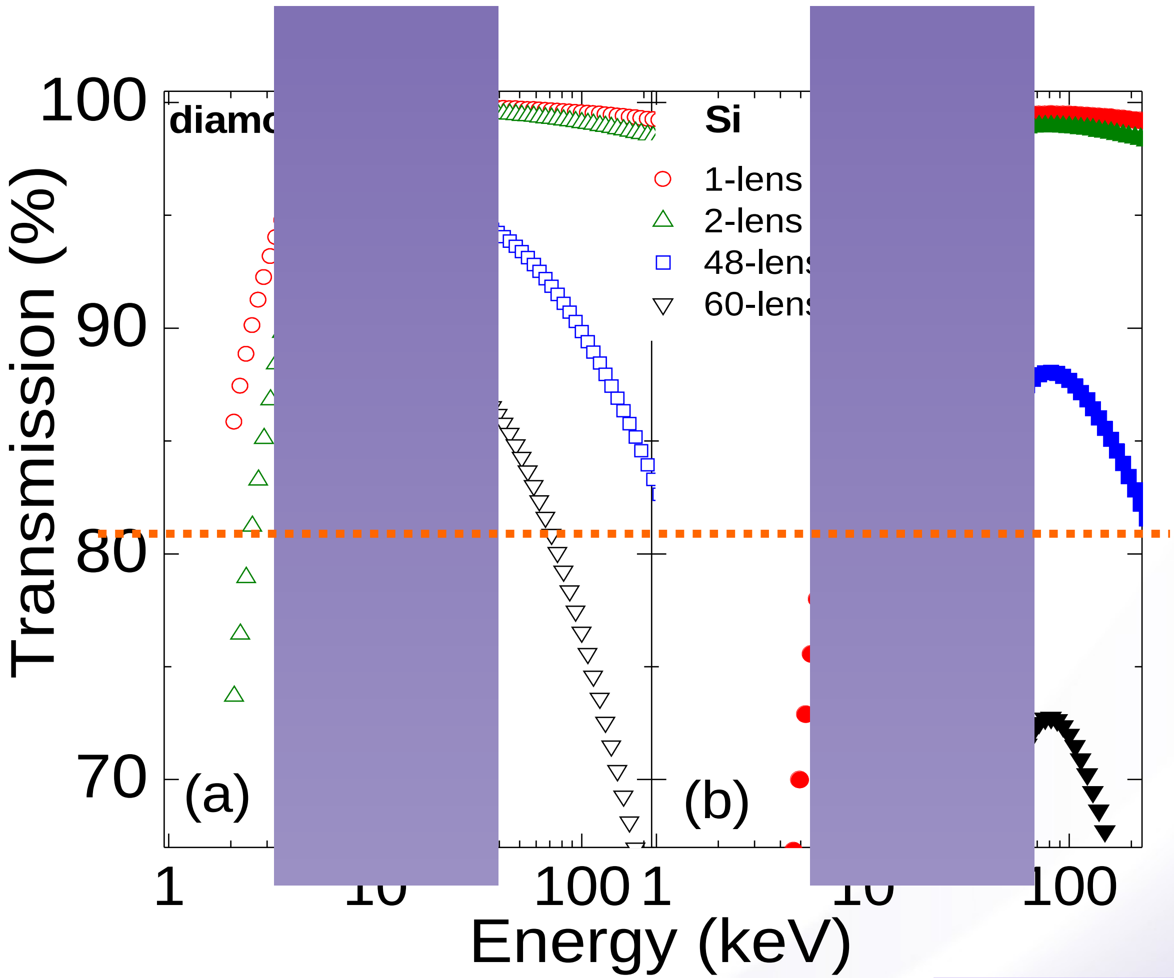
We can make prisms too





Now we have lenses and prisms,
Will allow “optical workbench”

Advantages of diamond for the same lens configuration. I



Source: NIST Tables and cross checked with CXRO <30keV
Compton + Photo-electric

A Diamond X-ray Lens!

Abdel Isakovic

From left to right: Aaron Stein, John Warren, Chris Jacobsen

John Warren